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Evaluation of soil nutrients under *Eucalyptus grandis* plantation and adjacent sub-montane rain forest

Shiferaw Alem • Tadesse Woldemariam • Jindrich Pavlis

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Abstract: A study was conducted to evaluate the status of soil nutrients under *E. grandis* plantation in comparison with that in its adjacent sub-montane rain forest. Twenty sequare plots, with an area of 20 m×20 m for each, were established in both of *E.grandis* plantation and its adjacent sub-montane rain forest, independently. Soil samples were collected from each square plot, at five points (at the four corners and at the center) of each plot. The collected soil samples were mixed to make a composite and representative sample for each plot, independently. The analyses were done in a soil laboratory following appropriate methods. The analysis result indicated that there were no significance differences between *E. grandis* plantation and its adjacent sub-montane rain forest in the level of major soil nutrients (total N, available P, exchangeable K, Ca and Mg), pH and total carbon of soils ($p < 0.05$). There were significance differences between two sites of forest soils in percentage of clay particles, and exchangeable Na content. *E. grandis* plantation was found improving soil nutrients and total carbon as compared with that of its adjacent sub-montane rain forest.

Keywords: *Eucalyptus grandis*; plantation; rain forest; soil nutrients; sub-montane

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Shiferaw Alem (✉)
Mendel University, Faculty of Forestry and Wood technology, Zemedelska 3/613 00, Brno, Czech Republic.
E-mail: shife19@yahoo.com

Tadesse Woldemariam
Environment and Coffee Forest Forum. P. O. Box 28513, Addis Ababa, Ethiopia.

Jindrich Pavlis
Mendel University, Faculty of Forestry and Wood technology, Zemedelska 3/613 00, Brno, Czech Republic.

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Introduction

To relieve the shortage of wood caused by the extensive deforestation, eucalypts were introduced to Ethiopia in 1894–1895 from Australia (Pohjonen and Pukkala 1990). These eucalypts were the most successful ones of the introduced plantation species and were quickly adopted by farmers, and widely distributed in the country. The reason for the widespread distribution was attributed to its fast growth, coppicing ability, and requirement of less management and its adaptability to a wide range of site conditions (Turnbull and Pryor 1978; FAO 1981). With increasing interest in eucalypt forest plantations as a source of wood and industrial fiber, concerns about the potential environmental impacts of establishing forest plantations of the species on a large scale are increasing. Specific concerns focus on potential loss of soil fertility and productivity under short harvest rotations and the associated impact on biodiversity (Jagger and Pender 2000).

The impact of tree plantations upon soil resources has been very much debated and any complete consolidated views don't exist, partly due to the fact that the impact is much dependent on variable site and forest conditions. Studies indicated that changes in some soil properties are influenced by tree species (Poore and Fries 1985; Lugo et al. 1990; Lemenih et al. 2004; Lemma 2006), stand age (Jaiyeoba 2001; Binkley et al. 2004; Zhang et al. 2004), biological factors (Burgess et al. 1993), and intensity of forest management (Shan et al. 2001; Mendham et al. 2002; Zhang et al. 2007). Species also vary widely in their inherent nutrient requirements and use (Cole and Rapp 1981).

Researches on soil nutrient removal of short rotation plantations with harvest were reported (Heilman and Norby 1997; Mulugata 2008) and information on above ground nutrient biomass and nutrient cycling are also available (Sing et al. 1989; Turner and Lambert 1983; Nsabimana et al. 2008; Marcela et al. 2009). A few studies were also conducted to determine the soil nutrients under *Eucalyptus globulus*, *Eucalyptus saligna*, *Pinus patula* and *Cupresus lustanica* (Mulugeta, 2008; Betre et al. 2000; Michelsen 1996). All these studies can give a clue on the impact of plantations on soil. However, extrapolation of these species and

site specific findings on other plantation species may mislead and draw a wrong conclusion. Rather, further studies on the effect of other fast growing plantation are important. Therefore, this study emphasizes on the status of soil nutrients under *E. grandis* plantation established in a high rainfall area. It was hypothesized that the soil under *E. grandis* plantation had less fertile than its adjacent sub-montane rain forest soil.

Materials and methods

Study area

The study was conducted in Belete state forest (7°31'N, 36°33'E) in the Southwestern part of Ethiopia, in the Jimma Zone of Oromia state. It has an altitudinal range of 1978 to 2113 m a.s.l and a rugged topography, dominated by gentle slopes and localized steep slopes from 4%–45%. The study area receives a mean annual rain fall of (1547±324.5) mm, with large inter annual variability. The mean annual temperature was 19.3°C, with a mean minimum of 13.3°C to mean maximum of 23.3°C. The hottest months occur from September to November (maximum 27.8°C) and the cold ones from June to August (minimum 12.8°C). Geologically, the study area is associated with Jimma volcanic, with abundant rhyolites and trachy basalts mainly overlie in the Precambrian basement (Tefere et al. 1999). The soils are Humic Nitosols with a clay loam texture and dark reddish brown color (FAO 2006).

The plantation was established in 1975, in a spacing of 2.5 m×2.5 m. Its seeds were imported from Australia and planted for adaptability research trial, in the locality. The *E. grandis* plantation was not harvested and its leaf residues and bark debris were left in the ground for decomposition and nutrient recycling. The density of naturally regenerated indigenous woody plants under the plantation was 3 842 stems·ha^{-1} , composed of 46 tree species, in which *Coffea arabica*, *Maytenus gracilips*, *Galiniera saxifraga*, *Clausena anisata* and *Millettia ferruginea* were dominant (Shiferaw and Tadesse 2009). The adjacent sub-montane rain forest was dominated by broad-leaved trees and the denisty of woody plants was 4 122 stems·ha^{-1}, belonging to 52 species, in which *Maytenus gracilipes*, *Galiniera saxfraga*, *Teclea nobilis*, *Clausena anisata*, *Vepris dainellii*, *Justia schimperana* and *Diospyros abyssinica* were dominant (Shiferaw and Tadesse 2009).

Sampling and analysis

Soil samples were collected in 40 square plots (20 m × 20 m), in five points (at the four corners and at the center) of each square plot, at the top 20 cm of the soil. Of the 40 plots, 20 plots were in the *E. grandis* plantation and the balance was in the adjacent sub-montane rain forest. The plots were laid out in a transect line along a gradient and the distance between consecutive plots within transect was 100 m, and the spacing between two adjacent transect lines was also 100 m. A compass was used for the alignment of transect lines.

The collected soil samples were mixed to make a composite and representative sample for each plot, independently. Composite soil samples were air-dried in an ambient air circulating cabinet in a shade and then sieved in a 2-mm mesh to remove coarse living roots and gravel. Soil texture was determined by Bouyoucos hydrometer method. Soil pH and Electrical Conductivity (EC) were measured with pH and EC meters, respectively. Exchangeable contents of Ca and Mg were measured after extraction using 1-M ammonium acetate at pH 7.0 and their concentrations in the extracts were determined using an atomic absorption spectrophotometer. Flame photometry was used to analyze K content of the soil (Black et al. 1965). Cation exchange capacity (CEC) analyses were done by instrumental finishing method. Organic carbon and total N was analyzed following Walkey and Black's titration method and Kjeldahl method, respectively (Schnitzer 1982). Available P was extracted with 0.1-M sulphuric acid and measured colorometrically by the ascorbic acid blue method (Olsen et al. 1954).

Data analysis

The data were analyzed using statistical SAS (9.1) software program (SAS 2003). Outlier results of soil data were removed before analysis. Each major plot soil indexes of the adjacent sub-montane rain forest and the *E. grandis* plantation were considered as a replication. Mean separation was done using Fisher's least significance difference (LSD) test with a significance level of p<0.05.

Results

The results of soil analysis are presented in Table 1. There were no significant differences in the level of major soil nutrients such as total N, available P, exchangeable K, Ca and Mg between the adjacent sub-montane rain forest and *E. grandis* plantation forests (Table 1). The percentage of clay particles in soil collected from the adjacent sub-montane rain forest was lower than that in the soil collected from the *E. grandis* plantation (p < 0.05). The exchangeable Na content of the adjacent sub-montane rain forest soil was lower than that in the *E. grandis* plantation forest soil (p<0.05). Whereas, there were no significant differences in the pH, CEC and organic carbon in soil (p < 0.05) between the adjacent sub-montane rain forest and *E. grandis* plantation. A significance difference was found in the EC between *E. grandis* plantation and adjacent sub-montane rain forest soil (p < 0.05). The average EC of *E. grandis* plantation was 0.12 ms·cm^{-1} while EC of adjacent sub-montane rain forest was 0.20 ms·cm^{-1}. Finally, there were no significant differences in the total silt and total sand percentage between the adjacent sub-montane rain forest and *E. grandis* plantation soils.

Discussion

Our results contradicted with a few comparative studies on soil nutrient under exiotic plantations (*E. globulus*, *E. grandis*, *E.*

saligna, *Pinus patula* and *C. lustanica*) and their adjacent natural forests (Betre et al. 2000; Michelsen et al. 1996; Maro et al. 1991). Those studies showed that pH, total N, available P, exchangeable Ca and Mg contents of soil in the adjacent natural forest soil were higher than those in soil of the plantations. Possible causes of the difference with the present study might be associated with the location of the plantation, age of the plantation, forest management activities and microclimatic condition. The *E. grandis* plantation was established in a high rainfall area which facilitates leaf litter decomposition and undergrowth vegetation. Shiferaw and Tadesse (2009) identified a total of 46 species of naturally regenerated native woody plants in the *E. grandis* plantation, with density of 3 842 stems·ha^{-1}. Therefore, the undergrowth native woody plants might have played a role in improving the soil fertility in combination with *E.grandis* residual waste debris. Ineson (1996) found out that leaves of *E. globulus* mixed with other species were decomposed in a faster rate as compared to *E. globulus* leaves only.

Table 1. Soil physical and chemical characteristics in *E. grandis* plantation and the adjacent sub-montane rain forest

Forest categories	pH	EC (ms cm^{-1})	Exch. Na (cmol+kg^{-1})	Exch.K (cmol+ kg^{-1})	Exch. Ca (cmol+kg^{-1})	Exch. Mg (cmol+kg^{-1})	CEC (cmol+kg^{-1})	Organic Carbon (g·kg^{-1})	Total Nitrogen (g·kg^{-1})	Available P (mg·kg^{-1})	Sand (%)	Silt (%)	Clay (%)
Sub-montane	4.94	0.20A	0.09A	1.77	15.26	4.22	40.02	5.55	0.68	9.56	40.30	41.27	18.44A
rain forest	(0.51)	(0.1)	(0.02)	(0.52)	(2.63)	(1.01)	(3.93)	(1.04)	(0.1)	(3.01)	(3.55)	(3.35)	
E.grandis	4.70	0.11B	0.11B	1.71	15.64	4.29	43.76	4.96	0.60	11.23	35.57	37.94	26.49B
plantation	(0.42)	(0.03)	(0.02)	(0.65)	(3.33)	(1.18)	(3.92)	(0.78)	(0.08)	(2.41)	(3.27)	(3.7)	
P in ANOVA	0.204	0.003	0.014	0.644	0.684	0.850	0.165	0.057	0.437	0.343	0.622	0.116	0.0001

Note: Means with different letters are significantly different at p=0.05. Exch. is exchangeable.

Lemma et al. (2007) calculated the amount of litter fall for *E. grandis* plantation as 10.1 Mg·ha^{-1}·a $^{-1}$. Similarly, Marcela et al. (2009) found that *E. grandis* leaves had the contents of N, P, K, Ca and Mg of about 17.9, 0.7, 5.9, 12.3, and 1.9 g·kg^{-1}, respectively while, its bark had the contents of N, P, K, Ca and Mg for 4.5, 0.2, 3.4, 26.6, and 1.6 g·kg^{-1}, respectively. It means that these nutrients recycled in the soil as leaf litter and bark residual wastes of *E. grandis* are allowed for decomposition which improves soil fertility. Mulugata (2008) found out a decline of soil nutrient concentrations (N, Ca and Mg) with the advancement of cutting cycles in eucalypt plantation. However, the *E. grandis* plantation was kept in the site for a longer time without harvesting, which means that soil nutrients were not removed with the advancement of cutting cycles.

Our data of soil organic carbon were supported by the findings of Bekele et al. (2006), who showed that *E. grandis* plantation, after 20 years of cultivation and 35 years of pasture, increased the total soil organic carbon to nearly pre-deforestation levels. Likewise, Ashagrie et al. (2005) found out that the bulk of soil organic carbon of *E. globulus* plantation at age of 21 was as similar as with that of its adjacent natural forest. These findings in combination with the present study can indicate that *E. grandis* plantation has the potential to improve the soil organic carbon if kept in the site for a longer time. Finally, it is possible to conclude that the *E. grandis* plantation which was established in high rain fall area and its leaf and bark waste debris left in the ground for decomposition does not depilate soil nutrients, as compared with its adjacent sub-montane rain forest.

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